cadmium isotopes.[14] It was found, as expected, that an equally good fit of the calculated to the observed crossings could be obtained if g_J was selected to lie within a few percent of this value. Level crossing experiments therefore, in fact, determine the ratio of the hyperfine interaction constants to the g_J factor of the state, and the g_J factor must be established by other means if the hyperfine constants are to be found to high precision.

NUCLEAR MOMENTS

The hyperfine anomaly for $Cd^{111,113}$ ($I=\frac{1}{2}$) has been shown to be only 1.6×10^{-5} from an atomic-beam investigation of the $^3P_2$ state.[15] It is not anticipated, however, that this effect will be so small for isotopes with different spins. For the cases of Hg^{199} ($I=\frac{1}{2}$) and Hg^{201} ($I=\frac{3}{2}$), and Xe^{129} ($I=\frac{1}{2}$) and Xe^{131} ($I=\frac{3}{2}$), also even-proton, odd-neutron nuclei, hyperfine anomalies of, respectively, 0.17 and 0.044% have been measured.[16,17]

We, therefore, cannot expect to determine the individual magnetic dipole moments of $Cd^{107,109}$ substantially more accurately from the known moment[18] of Cd^{111}, and the ratios of the A constants, than from the low-field double-resonance experiments. If we assume that the hyperfine anomaly of $Cd^{107,109}$ is comparable to that of $Cd^{111,113}$, however, we may calculate the ratio of the magnetic dipole moments to be

$$\mu_{107}/\mu_{109}=A_{107}/A_{109} =0.742997(8). \qquad (2)$$

To within the effect of hyperfine anomaly we may likewise calculate the ratio of the electric quadrupole moments to be

$$Q_{107}/Q_{109}=B_{107}/B_{109}, =0.98871(4). \qquad (3)$$

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Level Structure of Ni^{64}

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Excited states of Ni^{64} have been investigated through the study of the inelastic scattering of 11-MeV protons from an isotopically enriched target of Ni^{64}. Excitation energies of 30 levels between 1.34 and 5.49 MeV are reported. For the level at 3.55 MeV a spin and parity assignment of 3^- is suggested.

The excited states of Ni^{64} have been studied by measuring the inelastic scattering of protons from a Ni^{64} target, and the results have been compared with those recently reported by Benveniste, Mitchell, and Fulmer.[1] The Ni^{64} target was a self-supporting metal foil, ~1 mg/cm², enriched to 99.8% in the isotope. An 11-MeV proton beam from the ORNL Tandem Van de Graaff impinged on the target, and pulse-height spectra of the scattered protons were obtained at angles of 60, 80, 100, and 120 deg from the beam axis. The scattered protons were detected with surface-barrier silicon detectors, the over-all energy resolution being ~40 keV (full width at half-maximum).

Proton groups scattered by nickel were distinguished from those scattered by other nuclei (impurities) in the target and from alpha groups resulting from the (p,α) reaction by the characteristic change in energy with the angle of observation. To further distinguish between alpha and proton groups, a 2-mg/cm² aluminum absorber was placed between the target and the counter during one of two measurements at 80 deg.

The pulse-height spectrum obtained at 60 deg is shown in Fig. 1. Protons scattered by the first excited state of Fe^{56} ($Q=-0.845$ MeV) are clearly evident in this figure and indicate an iron contamination of

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
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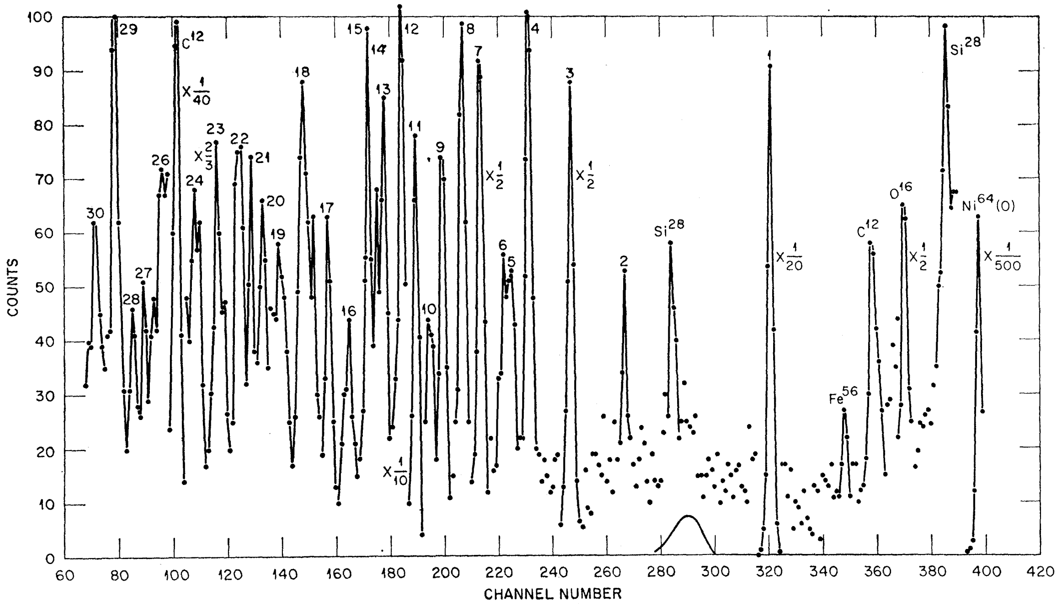

FIG. 1. Pulse-height spectrum of protons scattered by Ni^{64} at 60 deg. Peaks corresponding to Ni excited states are numbered and are identified in Table I. Peaks corresponding to protons scattered by a target impurity nucleus are marked with the symbol for that nucleus. The broad peak drawn between channels 280 and 300 shows the counter escape peak for the elastically scattered protons.

perhaps 1%. This contamination is much larger than was expected and must have been introduced during the fabrication of the target. Since other contaminants may also have been introduced, all four spectra were carefully searched for evidence of impurities. Except for Fe^{56} and the usual impurities C^{12}, O^{16}, and Si^{28}, none was found in sufficient quantity for positive identification, and it is highly unlikely that any numbered proton groups in Fig. 1 could result from proton scattering by nuclei other than Ni^{64}.

The pulse-height analyzing electronic system was energy calibrated by determining the channel positions of protons elastically scattered by Ni^{64} for several incident proton energies between 6 and 11 MeV. The positions of proton groups scattered by the target contaminants C^{12} and O^{16} were also used in the calibration. An error of 10 keV assigned to the excitation energies indicates our estimate of the reliability of the calibration. This error is larger than the maximum deviation of any individual measurement from the average value.

The energy of excitation was obtained at each angle for each group identified as inelastic proton scattering by Ni^{64}, and the values were averaged to obtain the excited states presented in Table I. In Fig. 1 the groups from nickel are labeled with the peak numbers corresponding to the associated excited states given in Table I. In some cases, indicated in Table I, the associated proton groups had widths >40 keV, and it is probable that these groups consist of more than one component.

A comparison of the results with the data of Benveniste *et al.*[1] is shown in Fig. 2. We did not observe a proton group corresponding to the excitation of a level in Ni^{64} between 1.79 and 1.88 MeV, as was reported by Benveniste *et al.*[2] Some of the counts shown for this energy region (between channels 280 and 300 in Fig. 1) were due to the excitation of the first level of Si^{28} ($Q=-1.78$ MeV) which was present on our target. The group appears as a sharp peak (channel 284 in Fig. 1), and its energy changes as a function of laboratory angle, in agreement with the

TABLE I. Ni^{64} excited states.

Peak No.	E_x (MeV)[a]	Peak No.	E_x (MeV)[a]
1	1.34	16[b]	3.95
2	2.27	17	4.08
3	2.61	18[b]	4.23
4	2.86	19[b]	4.37
5	2.97	20[b]	4.48
6	3.01	21	4.55
7	3.16	22[b]	4.63
8	3.27	23[b]	4.76
9	3.39	24	4.89
10[b]	3.48	25	4.99
11	3.55	26	5.11
12	3.64	27	5.21
13	3.74	28	5.28
14	3.79	29[b]	5.38
15	3.84	30	5.49

[a] An error of 10 keV is assigned to all levels.
[b] The proton groups associated with this level have widths larger than expected for a single level and may include scattering by more than one excited state of Ni^{64}.

[2] This level has been retracted by these authors, J. Benveniste, A. C. Mitchell, and C. B. Fulmer (private communication and to be published).

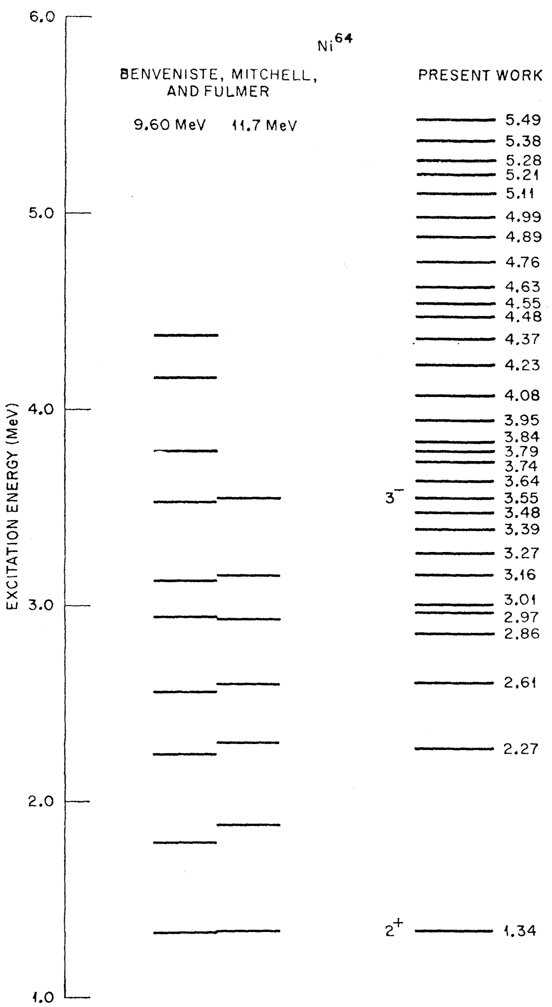

FIG. 2. Comparison of energy levels for Ni^{64}. The level shown by Benveniste, Mitchell, and Fulmer at about 1.8 MeV corresponds to the ground-state escape peak in the detector (see Ref. 2).

above identification. The corresponding elastic peak is also apparent (channel 386 in Fig. 1).

We also found in this energy region a broader group of protons which were due to reactions of the elastically scattered protons from the Ni^{64} with Si^{28} nuclei in the detector, leaving the Si^{28} nucleus in its 1.78-MeV excited state. The Si^{28} excited nucleus de-excites by the emission of a gamma ray which is not detected in the counter. This is an escape peak associated with this type of detector. The cross section for the excitation of the first excited state of Si^{28} reaches a maximum, approximately 450 mb, near $E_p=5.5$ MeV, and decreases nonuniformly to 180 mb at $E_p=11.0$ MeV.[3] Accordingly, about 0.1% of the 11-MeV elastically scattered protons should excite this state in the silicon detector and appear in the escape peak. A pulse-height spectrum taken at 20 deg, where the elastic cross section is large, clearly shows a broad peak of $\sim$230-keV width centered at about $Q=-1.89$ MeV on the Ni^{64} excitation energy scale. This width is due primarily to the resolution of the detection of the silicon recoil nucleus in the detector. The area of this peak is 0.1% of the area of the elastic peak; therefore, a correction of this magnitude and shape was applied to the data taken at each of the four angles. The curve drawn between channels 280 and 300 on Fig. 1 illustrates the subtraction at 60 deg. After this correction was applied to the spectra, there remained no statistically significant peak which could be associated with proton excitation of a level of Ni^{64} near 1.8 MeV.

Note the large cross section for the level at $Q=-3.55$ MeV (No. 11 on Fig. 1) compared to those for neighboring levels. The differential cross section for this level is quite similar in magnitude and shape to those obtained for 14.6-MeV protons scattered by the 3^- levels of Ni^{60}, Fe^{56}, and Zn^{64}.[4] On this basis, we suggest a spin and parity assignment of 3^- for this level. This Q value for the collective 3^- state is in disagreement with the value of -3.8 MeV found from (α,α') scattering by Beurtey *et al.*[5]

Analysis[6] of the angular distributions from the levels numbered 2, 3, and 4 on the basis of the vibrational model identifies them as being the two-phonon triplet having spins of 0^+, 4^+, and 2^+, respectively.

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